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Running title: Slurry management and ammonia loss

Abstract

In Spain, farmers are interested in applying pig (*Sus scrofa domesticus*) slurry (PS) to their fields throughout the year. During the spring and summer months ammonia (NH_3) volatilization may be high. We studied the potential range of NH_3 losses under a warm and a hot period of the year, using available field practices, and two strategies: PS directly incorporated into the soil, in spring (I-spring); and PS applied by splash-plate, in summer time (SP-summer), both to bare soil. Measurements were conducted, after PS application, using the micrometeorological mass-balance integrated horizontal flux method. The cumulative NH_3-N volatilization was 35% (I-spring) and 60% (SP-summer) of total ammonium nitrogen applied, and half of the total NH_3-N losses happened by 17h and 8h, respectively, after application. Incorporation strategy was less effective in avoiding NH_3 losses than is described in the literature. This fact has important consequences for the implementation of NH_3 mitigation measures in Mediterranean agricultural systems.

Keywords: ammonia-losses, slurry incorporation-method, ammonia volatilization, splash-plate, fertilizer strategies.

Introduction

Spain is the second largest pig producer in Europe and nearly 50% of Spanish pig production is concentrated in the Ebro river valley (MARM, 2013).

Pig slurry (PS) is mainly applied to maize (long cycle) at sowing (April-May) and to winter cereals at sowing (October-November) or as a sidedressing (February-March), leaving a gap of 5-6 months when applications are normally avoided. In irrigated areas, a second crop after the cereal harvest or the extension of the maize (short cycle) sowing period can cover this gap.

Despite the importance of quantifying European NH_3 emissions, little work done under Mediterranean conditions has been published on the topic (Génermont & Cellier, 1997; Sanz *et al.*, 2010) and existing articles do not cover the whole annual period, nor the range of typical conditions.

Our objective was to quantify NH_3 volatilization losses from PS applied according to two different strategies: i) direct incorporation in spring (I-spring), assumed to approximate to minimum likely losses, and ii) splash-plate application in summer time (SP-summer), taken to approximate to maximum likely losses.

Materials and methods

Two experiments were conducted in a representative area of the Ebro valley (41º 44´N, 0º 49´W, altitude 225 m) on bare ploughed soil (Table 1) before cereal establishment. The first was established on 16-17 May 2007. An incorporation machine was employed. Pig slurry incorporation was by a tube divided into three hoses (12 outlets), with a total application width of 4.80 m. Each outlet was located between two shares, the first one opened a slot in the soil and the one located at the back buried the applied PS at a depth of about 0.15-0.20 m. The second experiment was established on 2-3 August 2007 where ssurface PS spreading was by a tank fitted with a splash-plate; it was spread over the soil without incorporation. For each strategy (Table 2), three replicates were set up plus a control.

Weather in the experimental period has two limitations, in May with minimum average temperature (T) and maximum average relative humidity (RH), and in August with maximum T and minimum RH (Fig. 1).

The micrometeorological mass-balance integrated horizontal flux method was used, following the description and procedure given by Wood *et al.* (2000). Each rotating mast supported three passive NH_3 flux samplers mounted at three heights (0.375, 0.75, and 1.50 m) with the greatest height being 10% of fetch length, in agreement with estimates by Itier & Perrier (1976), which were confirmed by a previous field test. The ammonium solution obtained in passive samples was analyzed with a continuous flow analyser (AA3–Bran+Luebbe). Sampling started immediately after application and periodicity for the first day was approximately from 1 to 2h, at 3h, from 5 to 8h, at 12h and before 24h after application. Later on, the intensity of sampling decreased with time according to the declining of the intensity of NH_3 flux losses (Fig. 2).

Differences between strategies in NH_3-N cumulative emissions and also as a percentage of applied NH_4^+-N, were analysed using analysis of variance and LSMEANS test (p= 0.05). The statistical package SAS V8.2 was used for all statistical analysis.

Results and discussion

The average for cumulative NH_3 emissions, measured during the experiments, was 35% of total ammonium nitrogen (TAN) applied (99 kg NH_3-N/ha, 25% of total N) in the I-spring strategy and 60% of applied TAN (122 kg NH_3-N/ha, 42% of total N) in the SP-summer strategy (Table 2). Half of the maximum NH_3-N loss was estimated to occur by 17h and 8h after application in I-spring and SP-summer strategies, respectively (Fig. 2). For the SP-summer strategy the emission was in the upper ranges found in other studies (e.g. Sommer *et al.*, 2003; Rochette *et al.*, 2009) but according to Misselbrook *et al.* (2005), the slurry dry matter content in the SP-summer strategy can explain losses equivalent to 60% of applied TAN. Incorporation did not reduce volatilization as much as it was expected to, according to the results from other experiments (Huijsmans *et al.*, 2003), probably because dry soil conditions (Table 1) made it difficult to fully bury the PS, favouring NH_3 gas diffusion through it.

In the context of Mediterranean agricultural systems, the official advice to bury PS spread over land not later than 24h after application would not be fully effective in reducing NH_3 emissions, as more than 50% of applied TAN could already be lost during the first 24 hours after application. In addition, the low moisture content in the soil, in the hottest months of the year, limits the effectiveness of PS incorporation. New methods must be investigated and they should be orientated to the reduction of slurry-air contact (e.g. trail hoses) or/and to slurry infiltration enhancement (e.g. light irrigation). Nevertheless, their effectiveness will be influenced by soil carbonate content and this aspect needs further practical evaluation. This research is also necessary in the framework of models such as ALFAM (Søgaard *et al*., 2002) that do not fully cover the special aspects that need to be considered in Mediterranean environments.

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Figure Tables

Table 1. Physico-chemical soil average characteristics (0-0.30 m)

Table 2. Main characteristics[a] and rates of the pig slurries applied to each plot according to the two strategies: Incorporation in spring (I-spring) and Splash-plate in summer (SP-summer). Length of measurement periods and absolute emissions are included.

Figure Legends

Figure 1 (a) Wind speed average (m/s); (b) Relative humidity averages of air (%): maximum (RHmax), medium (RHmed) and minimum (RHmin); (c) Air temperature averages (ºC): maximum (Tmax), medium (Tmed) and minimum (Tmin), on a daily basis for a period from 2004 to 2010. The black round symbols (●) are associated to average meteorological data for the period of measurements in each experiment (May and August of 2007). There is a marked contrast between the two measurement periods and no rainfall occurred in either of the periods.

Figure 2. Cumulative ammonia emission (NH_3-N) as a percentage of total ammonium nitrogen applied (NH_4^+-N, TAN) and measured in two different strategies: slurry incorporated in May and slurry spread (splash-plate method) in August. Both trends were adjusted (***, $p<0.001$) to the Michaelis-Menten equation [$N_{NH_3}(t) = N_{max} * (t/(t + K_m))$, where: N_{NH3} (% of TAN) is the accumulative

ammonia loss at time (t); N_{max} (% of TAN) is the maximum amount of NH_3-N lost and K_m (hours) is the time to reach half of the total losses].

Table 1. Physico-chemical soil average characteristics (0-0.30 m)

Characteristics	Value
pH (potentiometry 1:2.5)[a]	8.3
Humidity (105º C, % w/w)[b]	1.8
Organic matter (Walkley-Black,% w/w)	2.1
Carbonates (Calcimeter Bernard method, % w/w)	39.0
Sand (0.05-2 mm, % w/w)	25.1
Silt (0.002-0.05 mm, % w/w)	53.6
Clay (<0.002 mm, % w/w)	21.3

[a] 1:2.5; 1 soil: 2.5 distilled water (v/v).

[b] Soil water content was similar in both periods of slurry application.

Table 2. Main characteristics[a] and rates of the pig slurries applied to each plot according to the two strategies: Incorporation in spring (I-spring) and Splash-plate in summer (SP-summer). Length of measurement periods and absolute emissions are included.

Strategy	pH (1:5)	Dry matter (kg/t)	Organic matter (kg/t)	Ammoniacal-N (kg NH_4^+-N/ha)	Total N (kg N/ha)	Rate (t/ha)	Sampling period (days)	NH_3-N loss (kg N/ha)
I-Spring	8.2	84.8	59.5	267	377	53	6 days	100.7
I-Spring	8.2	84.8	59.5	302	427	60	7 days	97.6
I-Spring	8.2	84.8	59.5	272	385	54	6 days	99.0
SP-Summer	8.1	86.4	60.2	168	239	36	10 days	102.0
SP-Summer	8.1	86.4	60.2	254	359	54	9 days	157.9
SP-Summer	8.1	86.4	60.2	187	266	40	10 days	106.3

[a] pH by potentiometry (1:5; 1 pig slurry: 5 distilled water); dry matter by gravimetric analysis at 105ºC; organic matter by calcination at 550ºC, Ammoniacal-N by modified Kjeldahl method and total N by Kjeldahl method.

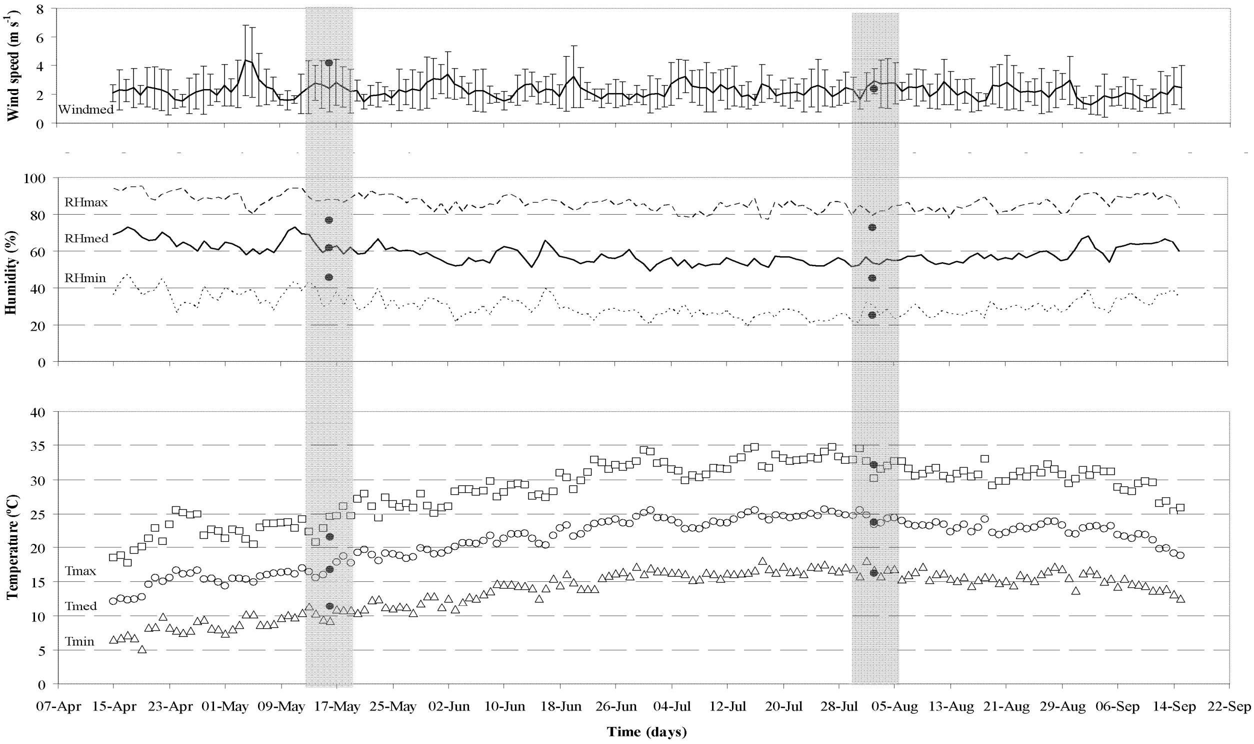
Wind speed (m s-1)
Windmed
Humidity (%)
RHmax
RHmed
RHmin
Temperature (ºC)
Tmax
Tmed
Tmin
07-Apr 15-Apr 23-Apr 01-May 09-May 17-May 25-May 02-Jun 10-Jun 18-Jun 26-Jun 04-Jul 12-Jul 20-Jul 28-Jul 05-Aug 13-Aug 21-Aug 29-Aug 06-Sep 14-Sep 22-Sep
Time (days)

Fig. 1

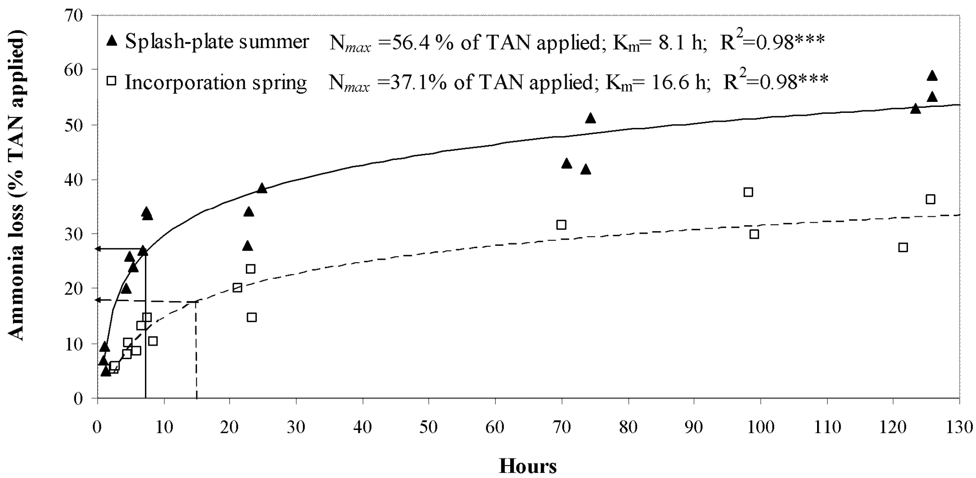
Splash-plate summer N max =56.4 % of TAN applied; Km= 8.1 h; R2=0.98***
Incorporation spring N max =37.1% of TAN applied; Km= 16.6 h; R2=0.98***
Ammonia loss (% TAN applied)
Hours

Fig. 2